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Do funding modes matter? A multilevel analysis of funding allocation mechanisms on university research performance

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Abstract

Over the last decades, most EU countries have profoundly reshaped their public research funding systems by shifting from traditional institutional block-funding towards more project-based mechanisms. The main rationale underlying this evolution builds on the assumption that project funding would foster research performance through the introduction of competitive allocation mechanisms. In contrast with the general increase of project funding, evidence is mixed regarding a positive effect of competitive funding mechanisms on research performance, as some studies find a positive impact, other a negative one or no impact. Differences also appear across studies regarding research actors, funding streams, and research outputs considered. This article integrates these different approaches through a multilevel design gathering funding inputs for 10 countries and 148 universities between 2011 and 2019 and assesses their impact on the quantity and quality of publications. Results highlight no impact of national and university-level competitive funding mechanisms on universities highly cited publications and no clear effect on the quantity of publications.

Keywords: research funding; competitive funding; research performance; multilevel analysis; research funding allocation mechanisms.

1. Introduction

Over the last decades, most EU countries have profoundly reshaped their public research funding systems by shifting from traditional institutional block-funding towards more project-based mechanisms (e.g. Boden et al. 2004; Lepori et al. 2007; Whitley 2007; Gläser and Laudel 2016). The main rationale underlying this evolution builds on the assumption by research funding authorities that project funding would foster both research performance and a more efficient use of financial resources through the introduction of competitive allocation mechanisms, in a context of scarcity of resources (e.g. Braun 1998, 2003; Geuna 2001).

In this article, we question the idea that project funding leads to improved research performance, as a number of characteristics of project funding may hinder rather than favor research excellence, including biases linked to short-termism, lower risks, and more applied rather than exploratory projects (e.g. Larrue, Guellec and Sgard 2018). In addition, specific features of institutional funding linked to stability, the possibility to develop longer term and more complex project, and foster career advancement may help to attract the best researchers and incentivize high-quality research outcomes (Heinze et al. 2009).

In contrast with the general increase of project funding over the last 40 years, empirical evidence regarding the positive impact of project funding on research performance is mixed. Some studies find a positive impact of project funding on scientific performance (Aghion et al. 2007, 2008, 2010; Ayoubi, Pezzoni and Visentin 2019), while others highlight that more competition would have no or a negative impact on the quality of research outputs (e.g. Himanen et al. 2009; Auranen and Nieminen 2010; Sandström and Van den Besselaar 2018). One specific characteristic of these studies rely on the variety of research actors and indicators of research quality considered. To what regards research actors, some analysis focus on countries and national performance (Himanen et al. 2009; Auranen and Nieminen 2010; Sandström and Van den Besselaar 2018), others focus on universities (Aghion et al. 2007, 2008, 2010) and others again on groups of researchers (Ayoubi, Pezzoni and Visentin 2019). In addition, the measurement of research outputs and quality also widely differ across studies, as some research focus on position within global research rankings (Aghion et al. 2007, 2008, 2010), other on the total number of publications (e.g. Auranen and Nieminen 2010), other still on citation metrics (Himanen et al. 2009; Sandström and Van den Besselaar 2018). In this article, we aim to integrate these different approaches by developing a multilevel design aiming first to highlight how research funding modes at national levels impact universities' research funding practices and secondly to what extent national and university funding allocation mechanisms impact universities research performance, both in terms of quantity and quality of publications.

On this basis, this article aim to answer the three following research questions:

1) What are the current patterns in the national composition of funding for research (institutional vs project-based) and their evolution over the last decade in the EU?
2) To what extent funding modes at national level are related to funding modes at university level?

3) To what extent national and university funding modes impact on university research performance?

To tackle these issues, this article first relies on funding data collected at national level through EUROSTAT and disaggregated by project and institutional funding. These data refers to the share of national institutional and project funding within Global Budgetary Allocations for R&D (GBARD). Secondly, data related to funding at university level is composed of statistics collected through the European Tertiary Education Register (ETER) on total revenues of universities and third-party funding as proxy of project funding. Finally, the third set of data refers to universities academic performance and stems from the Leiden ranking CWTS database. The matching of data at national and university level allowed to conduct a multilevel analysis of data for 10 EU countries (Austria, Belgium, Czechia, Germany, Ireland, Luxembourg, the Netherlands, Portugal, Slovakia, and Switzerland) and 148 universities for the years 2011–9.

The structure of the article is as follows. The conceptual background is introduced in Section 2. Data and method are described in Section 3. Section 4 first provides an analysis of funding modes in each of the 10 countries scrutinized. Secondly, it provides a multilevel analysis of funding allocation mechanisms in these 10 countries on research performance of the 148 universities considered. Results and their implications are discussed in Section 5.

2. Conceptual background

2.1 Nature and purposes of funding modes

Funding research policy frameworks traditionally differentiate between institutional funding and project funding (Lepori 2011). Institutional funding, also referred to as basic state installment, block grant, or general university fund, is defined as 'the funding of institutions with no direct selection of projects or programmes to be performed. Under this type of funding, it is the receiving institution that has discretion over the R&D projects that are to be performed, not the funding organization' (Van Steen 2012). The overarching purpose of institutional funding consists of maintaining a stable research infrastructure and underpinning long-term research. It leaves a large degree of academic freedom and autonomy to higher education institutions (HEIs) for funding their own research activities and is therefore generally not considered to be aimed to steer research towards specific national priorities (Larrue, Guellec and Sgard 2018). While institutional funding is traditionally considered as being non-competitive, the development of institutional performance-based research funding by most EU countries over the last decades has modified this aspect by progressively introducing some elements of competition. Performance-based funding (PBF) schemes refer to the competitive allocation of funding to research organizations (e.g. universities or other public research organizations) based on an ex-post assessment of their past research performance (e.g. Hicks 2012). Most EU Member States have introduced this funding mechanism within their funding policy framework over the last 20–30 years, although wide disparities persist with regards to the share of institutional funding allocated through this mechanism (Reale 2017; Zacharewicz et al. 2019; Jongbloed et al. 2023).

As opposed to institutional funding, project funding refers to 'money attributed to a group or an individual to perform an R&D activity limited in scope, budget and time, normally on the basis of the submission of a project proposal describing the research activities to be done. Whether the process of allocation is competitive or not is not decisive, since project funds can also be attributed through direct contracts.' (Lepori et al. 2007). Under this modality, funding is attributed on the basis of an *ex ante* assessment of future research. The selection of project proposals relies on a process in which public agencies or research councils decide to allocate funding with respect to a quality assessment and relying on a set of agreed criteria, generally through a peer-review process (OECD 2002; Besselaar and Leydesdorff 2009). Although the competitive component is not a fundamental definitory characteristic of project funding, since financial resources can be attributed on the basis of direct contracts to individuals or groups of scientists without structured comparisons across project proposals, project funding is most often considered as a competitive funding mechanism by policy makers, funding agencies, and academics.

Over the last 40 years, a widely held assumption has been that enhancing project or PBF mechanisms can lead to improvements in research performance by facilitating a more efficient use of funding resources. Efficiency here means that a better quality of scientific output (e.g. share of highly cited papers) by amount of financial input would be obtained through these modalities rather than through traditional institutional block funding. Several justifications are advanced to explain this hypothesis (Geuna 2001; OECD 2002; Tapper and Salter 2003; Hicks 2012; Zacharewicz et al. 2019).

First, a common argument is that project funding mechanisms would allow selecting the best research groups through *ex ante* assessments of project proposals based on a set of standardized criteria and informed peer-review evaluations. Among the wide array of possible evaluation criteria, the inclusion of past performance of research teams and organizations would foster the development of general incentives for all research actors to achieve better results and in turn become more competitive (Auranen and Nieminen 2010). This could therefore enhance the creation of a virtuous circle able to favor a systemic improvement of research outcomes.

Secondly, project funding mechanisms are also aimed to incentivize specific research topics of interest for public or private funding organizations and increase socio-economic impact of research. To do so, the conditional selection and monitoring of research projects according to their likely contribution to strategic objectives have become a key aspect of project evaluation (e.g. Whitley 2007).

Thirdly, beyond the capacity to get access to research funding, research teams and organizations can be sensitive to the reputational impact involved by their degree of success in funding opportunities. Among the underlying reasons why researchers and research organizations are motivated by these effects, is that their reputation has an influence on their future access to resources, such as the attractiveness of students, staff, or access to more project funding.

Fourthly, on the input side, the efficiency of project funding mechanisms would be enhanced by award criteria linked to total cost of projects, which would stimulate cost-minimizing behaviors and the need to overcome institutional rigidities to make the best use of funding received (Geuna 2001; OECD 2002).

In contrast to the above arguments supporting a positive effect of competitive funding on research efficiency and performance, another strand of analysis defends that increasing reliance on project funding can result in shorter-term, lower-risk and more applied projects, rather than longer-term, higher-risk and more exploratory research (e.g. Larrue, Guellec and Sgard 2018). One explanation is that while exploratory research could be perceived by research evaluators as more unlikely to produce tangible results, more applied projects would offer more guarantees and thus be more convincing when it comes to decide on whether or not providing research funding. In addition, while project funding is aimed to increase research efficiency, the preparation of research proposals is often more resource and time intensive than research based on institutional core funding (Osório and Bornmann 2022). Also, because of the uncertainty about future funding, researchers, and research organizations may be more reluctant to rely on project funding for their long-term planning. They may rather be more likely to fund more complex projects and possibly more impactful ones through institutional core-funding. This is especially true for project-based funding with low success rates (Larrue, Guellec and Sgard 2018). Project funding and *ex ante* assessment processes may involve adverse effects such as the distribution of funding among the community in control of the peer-review process (Reale and Zinilli 2017) or the development of monopolistic positions by some performers (Masso and Ukrainski 2009), which can in turn negatively affect research performance. Finally, the composition of project funding is likely to be one of the key aspects influencing the nature and quality of research outputs. The Public Funding of Research (PREF) project carried out by a consortium led by the Italian National Council of Research (CNR CERIS) on behalf of the European Commission provided a comprehensive analysis of public research funding in 40 countries between 2000 and 2014 (Lepori 2017; Reale 2017). The project provides fine-grained disaggregation of research funding by mode of allocation, managing organizations, and funding flows to performers. In particular, it focuses on data based on the European Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets (NABS) to show that EU project funding programmes can be grouped in the four categories of (1) instruments oriented towards economic innovation and the creation of market value (NABS 6), (2) instruments devoted to the general advancement of knowledge (NABS 13), (3) policy-oriented instruments (NABS1-5, NABS7-11, and NABS14), and (4) a mixed category used when funding instruments are so heterogeneous that a dominant orientation cannot be found (Lepori 2017; Reale 2017).[1] While this categorization highlights that the advancement of knowledge is one of the purposes of project funding, it also shows that social political targeting and steering of research are also key aspects of this modality of research funding (Ramos-Vielba, Thomas and Aagaard 2022). For this reason, project funding might be used for a variety of different purposes beyond breakthrough research, which might impact on the nature and academic quality of publications.

2.2 Evolution of funding modes over time. A strong increase of project funding

Since the early 1980s, the evolution of European research funding systems has been driven by the active role of states in defining scientific policy (Guston 2000; Braun 2003; Lepori et al. 2007; Van Steen 2012; Reale 2017). Specifically, there has been a shift from a model of delegating academic activity to the scientific community (both universities and public research institutions) to a model in which states aspire to direct and channel research towards socio-economic and political needs. To achieve this, project-based funding has emerged as a tool allowing institutions to guide research towards predetermined objectives. There is broad consensus on the significant increase in the use of project-based research funding since the early 1980s (Geuna 2001; Lepori et al. 2007; Aghion et al. 2010; Auranen and Nieminen 2010; Larrue, Guellec and Sgard 2018; Lepori and Jongbloed 2018; Sandström and Van den Besselaar 2018; Lepori and Antonioli Mantegazzini 2020). However, while this intensification of the use of competitive funding modalities has been observed in numerous countries, the scarcity of data and quantitative indicators allowing for international comparison of this trend and accurate measurement of the proportions of increase has also been highlighted (Lepori et al. 2007; Auranen and Nieminen 2010; van Steen 2012).

Since the mid-2000s, three main initiatives have attempted to overcome these limitations by developing internationally comparable indicators about public research funding modalities. The first initiative resulted from the work carried out by the European network PRIME (2004–8), promoted by the European Commission, which developed a theoretical framework and a method for measuring project-based research funding in six European Union countries between the late 1970s and 2002 (Lepori et al. 2007). The second initiative comes from the Organization for Economic Co-operation and Development (OECD) and consists of the work carried out by a network of experts in science and technology indicators (NESTI) to collect data on the two main modalities of institutional and project-based research funding between 2000 and 2008 in the countries of the organization (Van Steen 2012). Finally, the third initiative consisted of a project by the European Commission titled 'Public Research Funding' (PREF) that provides new data on these modalities between 2000 and 2014 (Lepori 2017; Reale 2017). Each of these three initiatives is described below.

The PRIME project developed an analysis of the similarities and differences among six European countries (Austria, France, Italy, the Netherlands, Norway, and Switzerland) concerning the volume of project-based funding, its proportion in total public funding, its composition through different funding instruments, programs and objectives, and the different forms of allocation of these funds. Secondly, the analysis reconstructed the evolution of project-based funding modality between 1970 and 2002 in the six countries considered. A considerable increase in project-based funding volume has been observed in all analyzed countries, both in nominal values and as a proportion of gross domestic product (GDP). This increase has been accompanied by a multiplication of funding programs in the areas of knowledge creation, innovation promotion, and socio-economic policy.

The OECD NESTI project complemented this approach by collecting data on the evolution of public funding in 17 OCDE countries between 2000 and 2008. Its results highlight two main observations regarding research public funding modalities. First, significant variations are observed in funding modalities within OECD countries. Over the period studied, countries such as Switzerland, Denmark, the Netherlands,

and Poland mainly relied on institutional funding (around 70% of total public funding), while Ireland, Belgium, and New Zealand allocate more than 50% of their public funding to project-based funding. Secondly and unlike the 1970–2002 period analyzed in the PRIME project, the period 2000–8 is generally characterized by a relative stability in funding modalities.

Finally, the PREF study analyzed the evolution of public funding modalities in 40 EU and non-EU countries between 2000 and 2014. Its results highlight a modest but significant increase of the use of project funding in most countries considered, as well as a high variability of the levels of institutional vs project funding across countries.

2.3 Research funding modes and academic performance

In contrast with the general increase of project funding over the last 40 years, empirical evidence regarding the effect of this specific funding mode on research performance is mixed. While a number of studies find a positive impact of project funding on research output (e.g. Aghion et al. 2007, 2008, 2010; Ayoubi, Pezzoni and Visentin 2019), others find no straightforward connection between financial incentives, the efficiency of university systems and publication productivity (Himanen et al. 2009; Auranen and Nieminen 2010) and a more recent study highlights a negative relation between project funding and scientific performance (Sandström and Van den Besselaar 2018).

Most of these studies focus on impact analysis of funding modes at national level on average national research performance (Himanen et al. 2009; Auranen and Nieminen 2010; Sandström and Van den Besselaar 2018), on assessing the effect of universities' funding modes on their research results (e.g. Aghion et al. 2007, 2008, 2010) or on the specific impact of funding grants on researchers' outputs (Ayoubi, Pezzoni and Visentin 2019). While this provides insights on specific dynamics at stake at each level, multilevel research design could help understand how national and university or researcher level funding are related and combine, have similar or different effects on research performance. This would in turn favor the development of more fine-grained policy adapted to the activity levels considered.

In addition, the variety of research results is also likely to be linked to the diversity of research outputs considered. Some studies finding positive results of project funding over performance focus on the use of composite Shanghai ranking indicators as a proxy of university research performance (e.g. Aghion et al. 2007, 2008, 2010). Since their inception in 2003, global rankings have been the object of criticism for their lack of clarity or biases in measuring research quality (e.g. Hazelkorn 2009; Vernon, Balas and Momani 2018). In particular, the Shanghaï ranking relied in 2010 on a compound of six different indicators to build an aggregate index of research performance (Aghion et al. 2010, p. 14).[2] While the authors point out that the indicators are highly correlated across each other, they also acknowledge the arbitrariness of their choice and of the weighting they are given in the composite indicator. Differently, other studies use the number of publications as research output and find no substantial effect of funding modes on national performance (Auranen and Nieminen 2010). While this approach allows providing insights on the evolution of funding modes and publication productivity, the authors recognize that 'the number of international publications is not synonymous with scientific quality' (p. 825). Finally, other studies focus on total number of citations, impact factors or top-cited papers to assess for the effect of funding mechanisms on research performance. Despite using similar performance indicators, these approaches highlight different effects, either positive for specific funding schemes and groups of researchers (Ayoubi, Pezzoni and Visentin 2019), negative (Sandström and Van den Besselaar 2018), or non-significant (Himanen et al. 2009) when taking into account national performance. To clarify whether financial inputs at different levels have a differential impact on university performance, the present research develops a multilevel design aiming to integrate research actors that have so far been considered independently.

3. Methodology

3.1 Data collection

The data collection is decomposed into two main steps, which are first the collection of data at national level and secondly at university level.

Regarding data at national level, statistics on institutional and project funding schemes are retrieved from EUROSTAT and from a European Commission study (Jonkers and Zacharewicz 2016; Zacharewicz et al. 2019). Each of these sources are presented as follows.

The Eurostat database provides GBARD data to measure government support to research and development (R&D) activities. These data are disaggregated by total amounts and shares of project and institutional funding. Within the total amounts provided, the sum of project and institutional funding amounts is equal to GBARD total amount, for which the share of GBARD not covered by project funding is covered by institutional funding and vice versa. GBARD total funding amounts were normalized by national inhabitants. Data were retrieved for the years 2010–20. Regarding institutional funding, no further disaggregation by block funding and PBF is available.

To cover this specific aspect, we will refer to and update data collected through to a previous study conducted by the European Commission (Jonkers and Zacharewicz 2016; Zacharewicz et al. 2019) to analyze information related to the implementation of institutional PBF within the European Union Member States. This study relied on inputs from a network of national experts located in each EU country for the purposes of a DG JRC Research and Innovation Observatory (RIO). The information provided was reviewed by National Contact Points appointed by the European Research Area and Innovation Committee. While the analysis of funding allocation criteria, formulas and peer-review processes would exceed the purposes of the present article, we will reflect here whether PBF are implemented in the countries analyzed and if so in which year they were introduced in the funding policy mix.

At university level, we retrieved funding data from the ETER database for the period 2011–9. Two variables were included. First, for budgetary data, we relied on 'the total revenues of universities'. Secondly, we relied on the variable 'third-party funding' as a proxy of project funding at university level. Third-party funding is defined as funding earmarked for specific activities and institutional units and in

most cases it is also limited in time (Lepori et al. 2007; ETER 2019). The main component of third-party funds are public research grants attributed by national and international funding agencies based on the competitive evaluation of proposals (Reale 2017; ETER 2019).

To assess the influence of national institutional and project funding schemes on universities academic performance, we gathered output variables at university level related to the total number of publications as well as to the percentage of academic papers situated within the top 10% highly cited papers (PP10), in fractional counting, for the years 2011–20. This choice is justified by the fact that this subset of total publication output is generally considered as the one representing frontier knowledge (Waltman et al. 2012). With regards to the PP10 dependent variable used, a difference needs to be made between the release year of publication and the citation window allowing for classifying publication within the top 10% most-cited. For this article, the citation window covers the period between the date of publication and December 2020. Data were disaggregated by universities and retrieved from the database built by the Leiden University Centre for Science and Technology Studies (CWTS). To reflect the time-lapse between funding inputs and academic publications, we opted to integrate a 1-year delay between funding inputs and publication outputs.

Four control variables were considered. The first two ones, GBARD per inhabitant at national level and total revenues of universities aim to reflect the established influence of research funding amounts on research performance (e.g. Auranen and Nieminen 2010; Sandström and Van den Besselaar 2018). The third control variable is the level of highly cited publications 1 year before the dependent variable is measured. This aims to reflect path-dependencies across levels of publication. Finally, we controlled for the implementation of PBF schemes in the countries considered through the inclusion of a dichotomic variable.

The matching of Eurostat for funding allocation at national level, ETER database for university-level funding and CWTS database for publication outputs leaves data available for 10 countries (Austria, Belgium, Czech Republic, Germany, Ireland, Luxembourg, the Netherlands, Portugal, Slovakia, and Switzerland) and 420 universities and HEIs for the period scrutinized. Out of these, we observed that many HEIs show very low levels of publications (e.g. applied universities, art, or music HEIs, etc.). In order to focus our analysis on research universities, we opted to select institutions with an annual publication record of over 100 scientific articles (in fractional counting). This leaves 148 institutions across the 10 countries considered (see Table 1).

Table 1. Selected sample of countries and HEIs

Countries	Number of universities
Austria	14
Belgium	5
Czech Republic	14
Germany	67
Ireland	8
Luxembourg	1
Netherlands	13
Portugal	11
Slovakia	4
Switzerland	11
Total	148

3.2 Analytical framework

Our data present a hierarchical structure such that university-level data are nested within countries. To analyze path-dependencies between funding data at national and university level and research outputs at university level, we adopted multilevel regression analysis for relationships among variables across hierarchical levels (Hox, Moerbeek and van de Schoot 2018). The model also included four control variables, being GBARD amounts at national level, total current revenues (TCR) of universities, PP10, and the implementation of PBF schemes. All input variables were included at year t, while output variables were included at year $t+1$.

To identify the effects of the different variables considered at national and university levels on research outputs, we based the analysis on three different models. First, we computed a mixed model analysis. We utilized a logarithmic transformation on variables expressed in absolute values to mitigate heteroscedasticity by stabilizing the variance across different levels of the variable. In addition, as project funding is expressed a share of total GBARD, we computed their interaction by multiplying the values of the two variables. The same process was applied at university level with the variable third party funding (expressed as a percentage of total revenues of universities) and total revenues of universities. We thus obtained the following model (here presented for PP10, but also applied to the total number of publications, P):

$$\begin{aligned} PP10_{ij}^{t+1} = {} & \Upsilon_{00} + \Upsilon_{01}.\text{lnGBARDperINH}_j \\ & + \Upsilon_{02}.\text{lnGBARDperINH} * \text{ProjectFunding}_j \\ & + \Upsilon_{03}.\text{PBF}_j + \mu_{oj} + \Upsilon_{10}.\text{lnTCR}_{ij} + \Upsilon_{20}.\text{lnTCR} \\ & * \text{TPF } \Upsilon_{30}.PP10_{ij} + \varepsilon_{ij} \end{aligned}$$

$PP10_{ij}^{t+1}$ = share of top 10% publications (PP10) within all publications of university i in country j (year $t+1$)

Υ_{00} = average/mean of the intercepts across groups (countries)

Υ_{01} = regression coefficient

lnGBARDperINH_j = GBARD per inhabitant within country j (log transformed)

Υ_{02} = regression coefficient

$\text{lnGBARDperINH*ProjectFunding}_j$: interaction between project funding (in % GBARD) and GBARD per inhabitant (log transformed) within country j

Υ_{03} = regression coefficient

PBF_j = implementation of a PBF system in country j

μ_{oj} = random component at national level/prediction error

Υ_{10} = regression coefficient

TCR_{ij} = total current revenues of university i in country j (log transformed)

Υ_{20} = regression coefficient

lnTCR*TPF = interaction between third party funding (TPF in % TCR) and total current revenues (TCR, log transformed) of university i in country j

Υ_{30} = regression coefficient

$PP10_{ij}$ = PP10 of university i in country j (year t)

ε_{ij} = prediction error

To further investigate the relationship and capture the peculiarities of the dependent variable (expressed as a share of total publications), we also explored a second specification of

the model using fractional logistic regression. In this model, we used a logit link function, which represents the logarithm of the odds ratio, thus enabling us to model the relationship between the independent variables and the probability of the dependent variable taking a value between 0 and 1. Moreover, to account for the nested structure of the data, we applied clustering of standard errors at country level. This clustering ensures that any potential correlation or heterogeneity within countries is appropriately considered in our analysis. This approach will provide insights into the fractional response nature of the dependent variable, offering a different perspective and enhancing our understanding of the factors influencing research outputs.

Finally, we explored the possibility of non-linear effects across variables by conducting a quantile regression analysis. This approach allows us to examine how the independent variables contribute to different segments of the distribution of the dependent variable. This aims to provide us with a more detailed understanding of how the effects of these independent variables may vary across different parts of the distribution.

These regression analyses were performed over the whole period under scrutiny (2011–9).

4. Results

4.1 Evolution of national funding environment

Over the last decade, the share of project and institutional funding has been highly stable in most of the countries analyzed (Table 2). In five out of the 10 countries considered (Czech Republic, Germany, the Netherlands, Austria, and Switzerland), the variation in the percentage of project funding within total GBARD is inferior to 5% between 2010 and 2020, while it is located between 5% and 10% for Belgium and Ireland. The same statistics is around 20% for Slovakia (high stability between 2012 and 2017, increase from 2018), while the variation is much higher for Luxembourg (65%) and Portugal (−28%). The average variation of the share of project funding within total GBARD across countries and over the period covered is of 5.80%. A regards national levels of project funding, two groups of countries can be identified. The first one gathers countries with a moderate level of project funding (between 20% and 40% GBARD) and is composed of Germany, Luxembourg, the Netherlands, Austria, Portugal, Slovakia, and Switzerland. The second group is composed of countries with a share of project funding close to or above 50%: Belgium, Czech Republic, and Ireland. This classification is in line with previous categorizations identifying substantial variations across countries (e.g. van Steen 2012; Reale 2017).

As no further disaggregation of institutional funding is available in Eurostat, we adapted data previously collected by Jonkers and Zacharewicz (2016) and recently updated (Teixeira, Biscaia and Rocha 2022) to identify whether institutional PBF was implemented in the 10 countries analyzed here (see Table 3).

In most countries identified, the implementation of PBF mechanisms preceded or coincided with a stabilization or a decrease of the share of project funding within GBARD amounts. While it is not possible to draw causal inferences between the introduction of PBF schemes and the levels of project funding, a possible influence cannot either be discarded. Regarding the modalities of the PBF schemes introduced, the funding allocation criteria relied on quantitative formula with bibliometric assessments in Belgium, Czechia, and Slovakia, while Portugal relies on peer-review assessment. In Germany and Switzerland, funding of universities is mainly provided at the regional level. These have increasingly included quantitative assessment criteria and/or performance contracts, but the nature of their funding allocation procedures differ from state to state (Van Daalen 2014).

4.2 University funding environment

Over the period studied, we observe a high heterogeneity across universities and countries in terms of the share of third-party funding within total revenues of universities (see

Table 3. Implementation of research PBF schemes

Country	Research PBF schemes	
	Introduced	Starting date
Austria	–	–
Belgium	×	2003 (Flanders), 2006 (Wallonia)
Czechia	×	2013
Germany	×	Difficult to assess—regional differences
Ireland	–	–
Luxembourg	–	–
Netherlands	–	–
Portugal	×	2015
Slovakia	×	2013
Switzerland	×	Difficult to assess—regional (cantonal) differences

Source: Adapted from Jonkers and Zacharewicz (2016) and Teixeira et al. (2022).

Table 2. Evolution of project funding in % GBARD 2010–20

Countries	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average growth rate (%, 2010–20)
Belgium	N/A	N/A	N/A	N/A	N/A	50.31	50.48	59.89	50.31	54.06	54.63	8.58
Czechia	48.73	54.82	52.39	50.78	51.98	51.61	50.02	50.67	49.74	50.5	48.59	−0.28
Germany	N/A	37.25	35.93	36.87	36.04	35.09	33.06	34.8	34.95	35.89	39.11	4.99
Ireland	66.21	64.5	63.4	67.74	64.97	66.58	65.74	64.49	64.46	61.09	61.28	−7.45
Luxembourg	14.65	18.15	17.04	15.13	17.24	21.72	21.08	25.34	25.65	30.4	24.17	64.98
Netherlands	30.84	30.37	29.16	29.37	28.31	27.6	30.77	29.96	33.43	32.99	31.27	1.39
Austria	N/A	28	26.79	27.33	28.22	28.82	27.8	26.47	26.89	25.33	27.69	−1.11
Portugal	38.47	33.09	34.64	24.98	27.63	32.2	30.73	28.15	27.75	30.97	27.65	−28.12
Slovakia	N/A	N/A	21.28	22.7	21.58	28.93	21.42	20.87	25.98	25.98	25.53	19.97
Switzerland	32.04	N/A	32.99	N/A	27.65	27.6	N/A	29.19	29.5	30.58	30.43	−5.02

Source: Eurostat. Consulted on 12 July 2022.

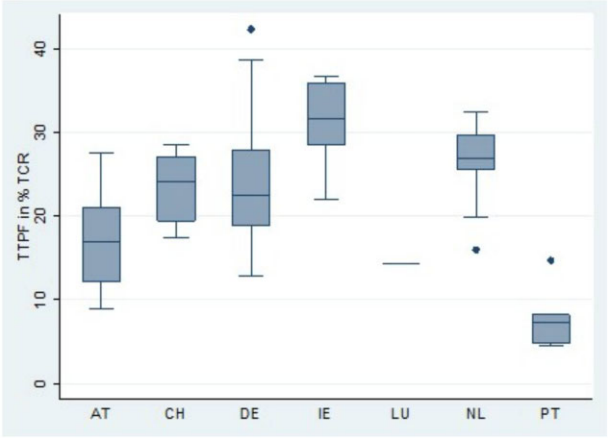

Figure 1. Heterogeneity in total third-party funding (TTPF) as a percentage of TCR among universities (2011). *Note*: No data are available for BE, CZ, and SK for 2011.

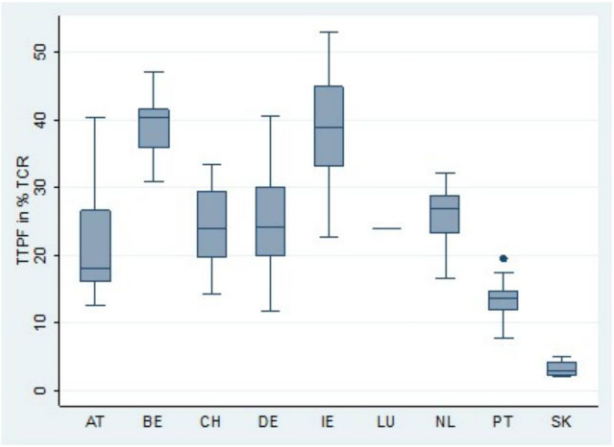

Figure 2. Heterogeneity in total third-party funding (TTPF) as a percentage of TCR among universities (2019). *Note*: No data are available for CZ for 2019.

Figures 1 and 2 for the first and last year of the period considered, 2011 and 2019). This means there is a high variability across universities and countries in the use of university level project funding (third-party funding). We then checked whether average levels of third-party funding in each country considered are related to annual levels of project funding. With this analysis, we aim to highlight whether national levels of project funding within total GBARD are related to average share of third-party funding within total revenues of universities. We find significant and relatively low to high correlations across the years, with a high variability across the years (see Table 4). Within the same period, the average correlation between third-party funding and total revenues of university also shows a significant and moderate level ($r = 0.28$, $P < 0.01$).

4.3 Multilevel analysis of the impact of funding modes on high-quality publications and total number of publications

Means, SD, and zero-order correlations for all the variables used in this study are shown in Table 5.

Table 4. Annual correlation levels between project funding and average third-party funding

Years	2011	2012	2013	2014	2015	2016	2017	2018	2019
Correlation levels	0.35	0.24	0.45	0.39	0.38	0.33	0.53	0.54	0.59

Note: All correlation values are significant at $P < 0.01$.

Prior to the analysis, we checked for possible collinearity issues across variables. First, the observation of the correlation matrix shows that none of the variables used in this study showed a correlation exceeding 0.90 with any other one. In addition, the variance inflation factor is below 10, for which we concluded to the absence of multicollinearity between variables (Myers 1990). We also checked whether the dependent PP10 and P followed a normal distribution. Skewness and kurtosis values were inferior to Kline's criterion of 1.5 (Kline 2005) and the observation of *Q*–*Q* plots showed no indices of non-normality.

We calculated intraclass correlations (ICCs) for PP10 and P. The purpose of this index is to determine whether there is significant clustering of observation for dependent variables across groups. For this, the ICC represents the proportion of total variance explained by the grouping structure (here, countries). It is generally admitted that levels of ICC below 0.05 are insufficient to conduct multilevel analysis as the difference among higher level units would be too small (Dyer, Hanges and Hall 2005). For this study, PP10 (ICC = 0.74) and P (ICC = 0.68) demonstrated substantial amount of between-group variance.

To identify the impact of the independent variables over PP10 and P and in particular of project funding (national level) and third-party funding (university level), we consecutively run a mixed model, a fractional regression model, and a quantile regression model on each dependent variable.

Regarding PP10, results are consistent over the three models. For the mixed model, we first assessed a model including the impact of GBARD per inhabitant on PP10 and observed a positive and significant effect ($\Upsilon = 0.90$, $P < 0.01$). We then progressively entered the additional variables into the model, starting by TCR of universities ($\Upsilon = 0.64$, $P < 0.01$). We observed a suppressor effect of the introduction of this variable on GBARD, as the latter lost its significance ($\Upsilon = 0.53$, $P > 0.05$) when TCR was entered. In the absence of collinearity issues between variables, this suppressor effect is probably linked to a moderation effect of TCR on the relationship between GBARD and PP10, as the national budget for research (GBARD) is likely to determine universities' revenues (TCR), which in turn positively affects levels and quality of publications (PP10). The remaining variables were then consecutively introduced without further mutual effect. Results show that neither national level project funding ($\Upsilon = 0.13$, $P > 0.05$) nor university level third-party funding ($\Upsilon = 0.01$, $P > 0.05$) have a significant impact on PP10 (see Table 6).[3]

To complement and confirm these results we run a second specification of the model using fractional logistic regression, with clustering of standard errors at country level. We followed the same process as for the mixed model to introduce independent variables and observed the same suppressor effect of TCR on GBARD.[4] The remaining results confirm the observations of the mixed model, as neither project funding

Table 5. Means, SD, and zero-order correlations across observed variables

Variables	M	SD	1	2	3	4	5	6
1. GBARD/inhabitants (in €)	294.13	139.22						
2. Universities TCR (in M€)	308.15	234.73	0.49*					
3. Project funding (%GBARD)	36.82	10.08	−0.39*	−0.15*				
4. Universities TPF (%TCR)	23.80	8.75	0.20*	0.28*	0.43*			
5. PBF	0.76	0.43	−0.05	−0.04	−0.03	−0.09*		
6. PP10 (% publications)	10.63	3.08	0.47*	0.60*	−0.19*	0.27*	−0.30*	
7. P (Total Number of Publications)	719.41	586.26	0.25*	0.84*	−0.14*	−0.29*	0.00	0.52*

Note: $N = 148$. TCR, total current revenues; TPF, third-party funding.
* Correlations are statistically significant at $P < 0.01$.

Table 6. Impact of GBARD, university revenues and funding modes on PP10 (2011–9)

Dependent var. PP10 ($t+1$)	Mixed model				Fractional regression model				Quantile regression model			
	Estimates (SE)	P > |z|	95% conf. interval		Estimates (SE)	P > |z|	95% conf. interval		Estimates (SE)	P > |t|	95% conf. interval	
			Lower bound	Upper bound			Lower bound	Upper bound			Lower bound	Upper bound
Intercept	−9.39 (2.46)	0.00	−14.21	−4.55	−4.11 (0.41)	0.00	−4.91	−3.32	−0.071 (0.02)	0.00	−0.10	−0.04
lnGBARD/inhabitant	0.39 (0.37)	0.28	−0.33	1.11	0.002 (0.04)	0.61	−0.06	0.11	0.001 (0.00)	0.14	−0.00	0.00
lnTCR	0.67 (0.09)	0.00	0.50	0.84	0.06 (0.02)	0.00	0.02	0.10	0.005 (0.00)	0.00	0.00	0.01
lnGBARDperINH* ProjectFunding	0.13 (0.38)	0.73	−0.60	0.86	0.01 (0.01)	0.79	−0.04	0.05	−0.000 (0.00)	0.97	−0.00	0.00
lnTCR*TPF	0.01 (0.04)	0.75	−0.06	0.08	0.00 (0.01)	0.46	−0.01	0.01	0.001 (0.00)	0.19	−0.00	0.00
PP10	0.45 (0.03)	0.00	0.40	0.50	6.27 (0.36)	0.00	5.58	6.97	0.674 (0.02)	0.00	0.62	0.72
PBF	0.42 (0.27)	0.13	−0.12	0.96	−0.06 (0.02)	0.00	−0.10	−0.03	−0.005 (0.00)	0.00	−0.01	−0.00
Residual (university level)	2.37 (0.11)	–	2.16	2.59	–	–	–	–	–	–	–	–
Residual (country level)	1.01 (0.68)	–	0.27	3.81	–	–	–	–	–	–	–	–

$N = 148$ universities.

($\beta = 0.01$, $P > 0.05$) nor third-party funding ($\beta = 0.00$, $P > 0.05$) significantly impact PP10 (see Table 6).

Finally, we considered the possibility of a non-linear effect of project funding and university third-party funding on PP10. To check for this hypothesis, we run a quantile regression analysis on the data, following the same introduction process of variables as for the two previous models. It first reiterated the suppressor effect of TCR on the relationship between GBARD and PP10. Secondly, it allowed to discard non-linear impacts of project funding ($\beta = 0.00$, $P > 0.05$) and third-party funding ($\beta = 0.00$, $P > 0.05$) on PP10 (see Table 6). We applied the same analytical procedure to the analysis of the total number of publications (P). The results were inconsistent across the three models and do not allow to draw clear conclusions on the impact the independent variables considered on P.

Regarding the mixed model and as for the analysis of PP10, we observed a suppressor effect of TCR on GBARD.[5] When introducing the remaining variables, we observed a negative effect of national project funding on the total number of publications ($\Upsilon = -0.03$, $P < 0.01$) but a positive effect of universities third-party funding ($\Upsilon = 0.01$, $P < 0.01$).

Before running the fractional logistic regression model, we normalized the dependent variable (P) so that its values are ranged between 0 and 1. As in the other cases, we observed the same suppressor effect of TCR ($\beta = 0.34$, $P < 0.01$) on GBARD ($\beta = -0.15$, $P < 0.01$). Differently to the mixed model, we found that neither project funding ($\beta = -0.00$, $P > 0.05$) nor university third-party funding ($\beta = 0.01$, $P > 0.05$) have a significant effect on the number of publications.

The quantile regression model still showed a different pattern, with a negative and significant effect of project funding ($\beta = -0.02$, $P < 0.05$) and a non-significant effect of third-party funding ($\beta = 0.00$, $P > 0.05$) on total number of publications (see Table 7). No clear conclusion can be drawn on the basis of these results on the impact of funding modes on the quantity of publications by universities.

5. Discussion

Through this article, we aimed to answer three main questions. The first one is related to the identification of current patterns in the national composition of funding for research, be it project or institutional funding- and their evolution over the last decade in 10 EU countries. The second question is related to the extent to which funding modes at national level are related to funding modes at university level. For this, our sample is composed of 148 universities located in the countries considered. Finally, the third question explores possible impacts of funding modes both at national and university level on the number and quality of papers produced by universities.

Regarding the composition of funding for research, the analysis of Eurostat data shows a stabilization of the share of project funding within total budget for R&D over the last decade. This highlights a change in funding policy as previous

Table 7. Impact of GBARD, university revenues and funding modes on P (2011–9)

Dependent var. P(t + 1)	Mixed model				Fractional regression model				Quantile regression model			
	Estimates (SE)	P > |z|	95% conf. interval		Estimates (SE)	P > |z|	95% conf. interval		Estimates (SE)	P > |t|	95% conf. interval	
			Lower bound	Upper bound			Lower bound	Upper bound			Lower bound	Upper bound
Intercept	−0.12 (0.09)	0.20	−0.30	0.06	−8.48 (0.76)	0.00	−9.99	−6.97	−0.32 (0.11)	0.00	−0.54	−0.10
lnGBARD/inhabitant	−0.12 (0.01)	0.03	−0.02	−0.00	−0.18 (0.06)	0.00	−0.30	−0.06	−0.02 (0.01)	0.01	−0.03	−0.00
lnTCR	0.02 (0.01)	0.00	0.00	0.03	0.35 (0.05)	0.00	0.25	0.46	0.03 (0.01)	0.00	0.02	0.05
lnGBARDperINH* ProjectFunding	−0.03 (0.01)	0.00	−0.04	−0.01	−0.00 (0.05)	0.96	−0.11	0.10	−0.02 (0.01)	0.00	−0.04	−0.01
lnTCR*TPF	0.01 (0.00)	0.00	0.00	0.01	0.01 (0.02)	0.73	−0.03	0.04	0.00 (0.00)	0.13	−0.00	0.01
P	0.98 (0.01)	0.00	0.97	0.99	0.00 (0.00)	0.00	0.00	0.00	0.97 (0.02)	0.00	0.95	0.98
PBF	0.00 (0.01)	0.48	−0.01	0.02	0.06 (0.03)	0.04	0.00	0.13	0.01 (0.00)	0.27	−0.01	0.02
Residual (university level)	0.01 (0.00)	–	0.00	0.01	–	–	–	–	–	–	–	–
Residual (country level)	1.15e−22 (3.95e−19)	–	0	–	–	–	–	–	–	–	–	–

$N = 148$ universities.

research had identified a clear increase of project funding at least since the beginning of the 1980s (Lepori et al. 2007; Van Steen 2012; Reale 2017). After the 2008 economic crisis, the decade 2010–20 has also been marked by a context of scarcity of resources and economic austerity measures, for which an increase of project funding levels could have been expected. Two possible explanations can be advanced to explain this change. First, after decades of increase, it may be possible that levels of project and institutional funding have reached a relatively stable equilibrium in which institutional funding provides accepted levels of stability within national systems while project funding provides enough flexibility. Secondly and complementarily, it may also be that the competitive share attributed to project funding switched to the institutional side through the development of research PBF systems. Throughout this study, we highlighted that at least four out of the 10 countries considered introduced PBF mechanisms since the mid-2000s (Belgium, Czechia, Portugal, and Slovakia[6]), for which PBF schemes may indeed be part of the explanation why project funding stabilized over time.

Secondly, we examined the composition of funding at university level and its possible relationship with composition of funding at national level. Our results show a high heterogeneity within and across countries with regards to the intensity of university third party-funding as a share of university total revenues. In addition, we also find that the use of third-party funding is modestly ($r = 0.24$, $P < 0.01$ for 2012) to highly correlated ($r = 0.59$, $P < 0.01$ for 2019) to national project funding over the period considered. This highlights that the research universities composing our sample implement different funding strategies to incentivize their research activities and that these strategies are not always in line with national funding policies. This legitimizes the third part of this analysis aiming to explore whether and how national project funding and university third-party funding have a differential impact on the quality and quantity of research produced by universities.

Previous research had focused on a variety of research indicators to assess whether funding amounts and modes have an impact on research outputs. Some relied on positions in global rankings (e.g. Aghion et al. 2007, 2008, 2010), other on the quantity of papers published (e.g. Auranen and Nieminen, 2010), others again on citation metrics (Himanen et al. 2009; Sandström and Van den Besselaar 2018; Ayoubi, Pezzoni and Visentin 2019). In addition, these research focused on different samples, either researchers (Ayoubi, Pezzoni and Visentin 2019), universities (Aghion et al. 2007, 2008, 2010), or countries (Himanen et al. 2009; Auranen and Nieminen 2010; Sandström and Van den Besselaar 2018). Mixed results were obtained and no clear pattern was observed with regard to the impact of funding modes on research outputs. Throughout the present article, we aimed to integrate these approaches by developing a multilevel design of funding modes at national and university level and by examining their impact both on the quantity and quality of research produced. To our knowledge, this approach is in itself a novelty, as no previous research has integrated the different actors involved in research nor examined the effects of funding inputs on different kinds of outputs.

Our analysis provide three main results. First, they confirm previous findings regarding the positive role of funding amounts on research outcomes, either being measured by the quantity of papers produced or by their quality. The analysis we conducted indicate a likely moderating effect of university revenues on the relationship between national budgetary allocations for R&D (GBARD) and research outcomes.

Secondly, the different regression models conducted converge in showing that neither national level project funding nor university-level third-party funding have a significant effect on the quality of publications—measured through the share of publications located within the top 10% most cited papers (PP10). These results challenge previous research suggesting that project funding has either a positive (e.g. Aghion et al. 2007, 2008, 2010; Ayoubi, Pezzoni and Visentin 2019) or a negative effect (Sandström and Van den Besselaar 2018) on academic performance and are in line with other studies finding no straightforward connection between financial incentives and the quality of publication (e.g. Himanen et al. 2009). Beyond these aspects, our results also deepen previous approaches by integrating country and university levels of analysis and by showing that positive effects of funding amounts and non-significant effects of funding modes on the quality of research are consistent across levels of analysis.

Finally, our results do not allow to clarify the impact of modes of funding on the quantity of publications.

These findings involve a number of considerations related to characteristics attributed to project or institutional funding modes at national or university level. First, none of these two modalities appears to have a differential impact on the quality of research. This is opposed to previous assumptions suggesting that project funding mechanisms could foster a selection of the best research groups through *ex ante* assessment of research proposals. Our results also challenge reverse statements according to which project funding would incentivize lower-risk and less groundbreaking knowledge, while institutional funding would drive attraction of the best researchers through longer-term and higher-risk exploratory research (e.g. Larrue, Guellec and Sgard 2018). Secondly, the present results also question assumptions related to the creation of a virtuous circle in which project funding would incentivize the achievement of high-quality results that would in turn allow for the obtention of more project funding, as our analysis does not support the dependency of highly cited publications on the nature of research funding received. In addition, while our findings highlight an absence of impact of modes of funding on high-quality publications, they cannot discard possible effects on other types of outcomes. As shown through the PREF study (Lepori 2017; Reale 2017), the policy purposes underlying the composition of project funding are heterogeneous across countries and change over time. Substantial financial amounts allocated to project funding mechanisms are meant to increase innovation activities, others are meant to steer research towards specific policy priorities and societal contributions (Ramos-Vielba, Thomas and Aagaard 2022), while some additional part of funding is also meant to foster the general advancement of knowledge. The analysis of project funding as a homogenous category does not allow to disentangle the diversity of these policy purposes and their actual impact on research outputs. In addition to issues linked to the diversity of samples (countries, universities, or researchers) and of dependent variables (number of publications, citation metrics, position in global rankings) used in the different studies, heterogeneity in the composition of project funding across actors and countries and its evolution over time may also be one of the reasons why no clear effect on research production emerges across studies. In this context, more fine-grained analysis of project funding and the different funding instruments that compose it may provide further insights on this specific issue.

At political level and in the absence of differential effects of modes of funding on research quality, our results provide support to the stabilization of the share of project vs institutional funding observed since 2010, after three decades of increase of project funding (Lepori et al. 2007; van Steen 2012; Reale 2017). In addition, further political implications of our findings are linked to definitory characteristics of project and institutional funding. One of the main difference between these two funding modes is that institutional funding provides stability to national and university research system, while project funding provides more flexibility, as it allows national authorities and funding agencies to steer research activity towards specific policy objectives. Related to this aspect, a second difference is linked to the actors impacted by institutional and project funding. While institutional funding addresses universities, project funding addresses individuals, or networks of researchers. As such, both levels of incentives are required, one to foster overall quality of universities and concentrate excellence in few places (e.g. through the development of institutional PBF schemes), the other one to spread knowledge across researchers and places (Dasgupta and David 1994). In the current context in which our findings highlight no impact of funding modes on research quality, the decision to concentrate or spread financial resources across institutions and researchers is dependent on contextual characteristics and policy purposes of each country, government and academic institutions.

Finally, whereas the multilevel design of our study allows for assessing the effect of funding variables on university academic performance, the need for combining data at different national and university levels limited the size of the analyzed sample. Whenever further data are available, we recommend replicating the analysis to confirm current findings on the absence of impact of funding modes, both at national and university levels, on the quality and quantity of university research outputs.

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Notes

1. NABS01: exploration and exploitation of the earth; NABS02: environment; NABS03: exploration and exploitation of space; NABS04: transport, telecommunications, and other infrastructures; NABS05: energy; NABS06: industrial production and technology; NABS07: health; NABS08: agriculture; NABS09: education; NABS10: culture, recreation, religion, and mass media; NABS11: political and social systems, structures, and processes; NABS14: defense.
2. (1) The number of alumni from the university who have won Nobel Prizes in physics, chemistry, medicine, or economics or Field Medals in mathematics (10% of the overall index). (2) The number of faculty of the university who have won Nobel Prizes in physics, chemistry, medicine, or economics or Field Medals in mathematics (20% of the overall index). (3) The annual number of articles authored by faculty of the university that are published in the journals Nature or Science (20% of the overall index). (4) The annual number of articles authored by faculty of the university that are in the Science Citation Index-expanded and Social Science Citation Index (20% of the overall index). (5) The number of Highly Cited Researchers (copyright Thomson ISI, 2008) in the university's faculty in 21 broad subject categories (20% of the overall index). (6) All of the above indicators divided by the number of full-time equivalent faculty (10% of the index).
3. When referring to project funding and third-party party, we refer respectively to the interaction of project funding with the log transformed GBARD and to the interaction of third-party funding with the log transformed total revenues of universities. The same formulation is used throughout the different specifications of the model.
4. When GBARD was entered as the only independent variable, it showed a positive effect on PP10 ($\beta = 0.29$, $P < 0.05$). This effect lost its significance ($\beta = 0.04$, $P > 0.05$) when TCR was entered into the model ($\beta = 0.06$, $P < 0.01$).

5. When GBARD was entered as the only independent variable, it showed a positive effect on P ($\Upsilon = 0.32$, $P < 0.05$). This effect became negative ($\Upsilon = -0.02$, $P < 0.05$) when TCR was entered into the model ($\Upsilon = 0.02$, $P < 0.00$).
6. It is more difficult to provide a clear assessment for Germany and Switzerland, where research funding policy is regionalized.

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